Time-Dependent System Reliability Methods and Applications

CEVE 424/524 – Fall 2020
MWF 9:45 AM – 10:40 AM, Keck Hall, Room 102

by
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Course overview:

This course is about thinking how engineered systems fail, how to quantify the odds of such failures, and learning from contingencies to design new or retrofit existing systems. The ultimate goal is to improve complex systems' risk-based reliability and resilience.

To achieve the course goals, students will learn modern computational and analytical methods to quantify the reliability of engineering systems as a function of their component probabilities of failure. Students will also learn how importance measures from reliability analyses are useful in engineering design and decision making. The course will cover topics on system reliability and their time evolution, while providing insights into emerging modeling techniques, algorithms, and their computational complexity. We will see the impact of reliability analyses on practical load combinations for design and associated normative design standards or recommended guidelines. The course emphasizes structural infrastructure components and their host systems or networks, which will be used as case studies. These include power systems, water networks, wind turbines, bridges, and buildings, among others.

Graduate students will work on expanded-scope homework sets and projects, as well as extra questions on tests.

Course outcomes:

Students completing the course should be able to:

1. Compute the probability of failure of complex engineering systems (structures and networks) with enough accuracy within a feasible amount of time.
2. Identify which technique, either simulation based or closed-form, is most suitable to tackle a given system reliability assessment problem.
3. Find system components that contribute the most to system-level reliability through a variety of importance measures.
4. Quantify the effects of time on the evolution of reliability, strength, and resistance of engineering systems.
5. Communicate, both in writing and orally, complex technical concepts on system reliability, resilience, and risk to expert and non-expert audiences.

Course topics

- Introduction to system reliability
  - Definitions
  - Current applications
- Review of probability theory
  - Mathematics of probability
  - Models of random phenomena
  - Functions of random variables
- Simulation methods
  - Monte Carlo
  - Optimal Monte Carlo
  - Las Vegas
- Time-evolving systems
  - Markov chains
  - First-passage probabilities
  - Outcrossings
  - Dynamic reliability
- System safety and reliability
  - Reliability index
  - First-order reliability method (FORM)
  - Second-order reliability method (SORM)
  - Probability bounds
- Network reliability
  - Fault trees
  - State-space partitions
  - Recursive formulations
  - Tensor networks
  - Classical and quantum counting
- Structural and infrastructure design standards
  - Event trees
  - Code development and calibration
  - Community resilience guidelines

Main references

[1] Melchers, R. E., and A. T. Beck, (2017). *Structural Reliability Analysis and Prediction*. 3rd Ed. John Wiley & Sons.

[2] Rausand, M., and A. Hoyland, (2004). *System reliability theory – Models, statistical methods and applications*. 2nd ed. New Jersey: John Wiley & Sons, Inc.

Supporting references

Books

[3] Ang, Alfredo H.-S., and Wilson H. Tang, (2006). *Probability concepts in engineering, emphasis on applications to civil and environmental engineering*. 2nd Ed. New Jersey: John Wiley & Sons.

[4] Gertsbakh, I. B., and Y. Shpungin, (2016). *Models of Network Reliability: Analysis, Combinatorics, and Monte Carlo*. CRC Press.
[5] Nowak, A.S., and K.R. Collins, (2013). *Reliability of structures*. 2nd Ed. Boca Raton: CRC Press, Taylor and Francis group.
[6] Ross, S., (1995). *Stochastic processes*. 2nd Ed. New York: John Wiley & Sons, Inc.
[7] Ditlevsen, O., and H.O. Madsen, (1996). *Structural reliability methods*. Chichester: John Wiley & Sons, Inc.

Journals
Instructor and students will periodically assess the literature on reliability and performance of structure and infrastructure systems, and identify papers for class discussion, homework assignments, and in-class work. Examples include:

- *ASCE/ASME Journal of Risk and Uncertainty in Engineering Systems*
- *IEEE Transactions on Reliability*
- *Probabilistic Engineering Mechanics*
- *Structural Safety*
- *Reliability Engineering & System Safety*

Course grading

Homework	40%
Mid-term examination	25%
Final Project	35%

Academic honor code

The Honor System embodies the concept of personal honor in a framework of law and practice. To quote the Constitution, Rice students are placed on their honor by the group "not to violate the trust placed in them in any way."

The result is a system of conducting examinations, writing papers, and performing other academic endeavors with regard for individual honor and without faculty proctoring. Thus, the responsibility for maintaining the validity of academic work is placed on all students. (Website with additional details: http://honor.rice.edu/).

Disabilities

Any student with a documented disability needing academic adjustments or accommodations is requested to speak with the instructor during the first two weeks of class. All discussions will remain confidential. Students with disabilities will need to also contact Disability Support Services in the Ley Student Center.

Office hours

- Mondays 1:00 PM – 2:30 PM (T.A.'s)
- Wednesdays 2:00 PM – 3:00 PM (Prof. Duenas-Osorio)